November 1983

DCIEM No. 83-R-56

DETECTION OF SIMULATED SONAR LINE TARGETS IN FREQUENCY-TIME-INTENSITY DISPLAYS WITH REDUCED DISPLAY AREA

S. M. McFadden
M. M. Taylor
C. D. Fast

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
Downsview, Ontario M3M 3B9

DEPARTMENT OF NATIONAL DEFENCE - CANADA

Table of Contents

ABSTRACT 1
INTRODUCTION 2
- Background 2
- Present Study 5

METHOD 5
- Observers 5
- Apparatus 6
- Stimuli 6
- Conditions 7
- Procedure 7

RESULTS 9
DISCUSSION 13
CONCLUSION 13
REFERENCES 14
APPENDIX A 15
APPENDIX B 17

ABSTRACT

Single target lines were detected against a background of white noise in a simulated sonar frequency-time-intensity display. The study evaluated the effect of reducing the total area of the display. Display size was reduced either by ORing together adjacent frequency bins or by reducing the number of independent time samples displayed. ORing ratios of 1:1, 2:1, and 4:1 and histories of 20 through 400 time samples were used. Detection performance was a function of total display area for history durations longer than 20 time samples. Reducing the number of pixels displayed by reducing the amount of history displayed or by ORing had an equivalent effect. Each halving of display area caused a 1.5 dB reduction in detectability of the target line.

INTRODUCTION

Background

The Frequency-Time-Intensity (FTI) display is useful for displaying the information picked up by passive sonabuoys. It is used primarily to detect and classify targets emitting stable narrowband sounds. The FTI display has been proposed also as a main display technique for towed array sonar systems, which provide much more information than does a simple sonabuoy.

The FTI display shows the output of 'x' narrowband filters over 'y' previous time periods. The average energy in the acceptance band of a single filter, or "frequency bin", over the duration of a time bin is shown by the brightness (darkness on a paper display) of a single spot on the display. The energies in all frequency bins for a single time bin are displayed as a single horizontal line, and many such lines are displayed to represent the patterns of energy change over history.

For best signal-to-noise ratio, the bandwidth of the filter should be matched to the probable bandwidth of the incoming signal. The minimum temporal resolution (the duration depicted by one history line in the display) is fixed by the filter bandwidth. The minimum area required to display all the available information requires one pixel (picture element) per filter along each history line, and one history line for each time period displayed. The actual frequency resolution and length of history displayed depends on the medium (CRT or paper), and on the amount of information to be displayed.

On a paper display, the available history is limited by the length of the paper, and the number of frequency bins by the width of the paper. Some trade off is usually necessary between frequency resolution and frequency range. On a CRT, it is necessary to limit the history displayed as well as the number of frequency bins, but it is possible to increase the range or resolution in one dimension at the expense of the other. The frequency range and resolution can be increased by displaying two or three bands of frequencies with short histories, or history duration can be increased by compressing each frequency band into a narrow strip or by limiting the range of frequencies displayed, as shown schematically in Fig 1(a-c).

A CRT is even more limited as a display space for sonar systems that can extract information from different sectors of the ocean separately. Such multi-beam systems, exemplified by towed-array sonar, provide much lower signal-to-noise ratios than do omni-directional systems, and hence in principle permit target detection at long ranges. On the other hand, the operator has much more data to scan. A multi-beam sonar system requires multiple displays which must be sequenced over time or displayed concurrently on a CRT, or both. To display the data from several beams simultaneously on a CRT, the area devoted to any one beam must be reduced. Display area can be reduced by reducing the number of frequency bins or the number of time bins displayed.

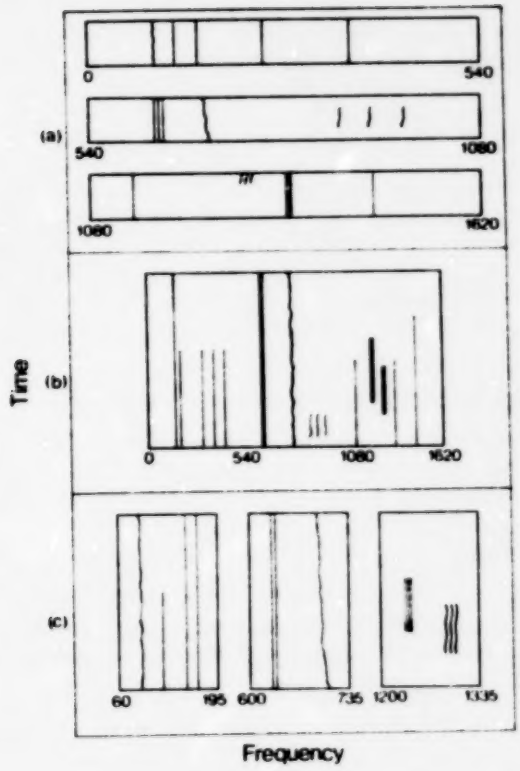

FIGURE 1: Three methods of formating a frequency-time-intensity display of passive sonar data. In (a) the total frequency range is displayed and frequency resolution is optimum. The history duration is limited. In (b) 4:1 ORing has been used to reduce the information presented along the x dimension. In (c) three subsets of the total frequency range are displayed. With (b) and (c), four times as much history can be displayed as in (a).

There are different ways of reducing display area and of presenting information sequentially to the screen. Some suggested alternatives include:

1. *Reduction in number of frequency bins displayed*:

   - *Reducing frequency resolution* : Increase the intrinsic bandwidth of the initial filters. Fewer frequency bins will be required, but a frequency bin will contain more noise than it would with the narrower filters, resulting in greater masking of the signal.
   - *Reducing overall frequency range* : Display a smaller set of frequencies. If the incoming signals are concentrated at certain frequencies, reducing the set of displayed frequencies should have little effect, because the omitted frequency bands will contain no interesting information.
   - *Frequency ORing* : From each successive group of K consecutive frequency bins display only that bin with the greatest intensity. If a signal is present, the bin with the greatest intensity in a group will probably be the one containing it. This method does worsen the signal-to-noise ratio, but not as badly as does the method of increasing the filter bandwidths.

2. *Reducing number of time bins displayed*:

   - *Reducing temporal resolution* : Display the output of a frequency band averaged over a larger time period. Fewer time bins will be needed to display the same duration. Any transient changes in an incoming signal are likely to be averaged out.
   - *Reducing the length of history displayed* : Less history will be available to the operator on which to base a decision as to whether an apparent line is target or noise.
   - *Temporal ORing* : The same as frequency ORing, but selection of the maximum is made along the time dimension.

3. *Sequential presentation methods*::

   - *Scrolling* : The operator may use the display screen as a moving window that can scroll across a larger virtual display. Moving the "window" may permit him to see a wider range of frequencies than can be shown at one time, or may show older history when desired.
   - *Paging* : Paging means presenting only part of the information on a single display and allowing the operator to call up successive discrete pages of information such as from different ocean sectors (beams). The difference between paging and scrolling is that paging moves among separate discrete display pictures whereas scrolling moves the physical picture continuously over the large conceptual picture.

Present Study

A sequential display may require expensive display subsystems and massive rapid-access storage. This makes it difficult to study and potentially unrealistic to implement in the near future. Methods that reduce the total number of frequency or time bins displayed are more likely to be considered. The present study compared what seemed likely to be the best methods from the first two groups: reducing the number of frequency bins through frequency ORing and reducing the number of time bins displayed. ORing is likely to be less detrimental than reducing frequency resolution and provides a more general purpose display for detection than reducing frequency range. Limiting the number of time bins displayed minimizes processing time and storage space required for past history.

The study measured the detectability of a single target line in white gaussian noise at seven different history durations ranging from 20 to 400 time bins and at three ORing ratios: 1:1, 2:1, and 4:1. A target line was either stable in frequency, in which case it appeared as a straight vertical line on the display, or unstable, in which case it deviated irregularly in slope.

Frequency ORing and reducing the number of time bins are complementary ways of reducing the display area, in that given information about 'x' frequency bins over 'y' times samples, the required display area can be halved either by halving the number of time samples displayed or by using 2:1 frequency ORing. Each method permits two beams to be displayed in the area originally allotted to one. If either method gives appreciably better performance than the other, it should be used when display space is at a premium. In fact, the experiments showed no clear advantage for either method. Detection of a single line in white gaussian noise was a function of the total number of pixels displayed, for history presentations in excess of 20 time bins. Reducing the number of pixels by reducing the amount of history or by frequency ORing had an equivalent effect if the number of time bins was between 40 and 320. Each halving in the number of pixels caused a 1.5 dB decrement in detectability.

METHOD

Observers

A total of seventeen observers participated in the study. At least five observers were used in each of the main conditions. Observers ranged in age from 18 to about 45. All had normal or corrected to normal vision. Observers included laboratory personnel and paid volunteers.

Apparatus

An FTI display was simulated using the Norpak Research Display System (RDS) (Taylor and Norton, 1977), connected to a PDP 11-34 running under the UNIX[1] timesharing system. The RDS can display scenes of arbitrary complexity, in which the colour and brightness resolution of the image are controlled by look-up tables loaded by the host computer.

The FTI display was presented on a Conrac high resolution colour monitor capable of displaying 1200 by 1000 pixels. The monitor was scanned in a normal television mode with a digital pixel resolution of 512 by 480 visible pixels. Fewer pixels were used in each experimental display. A preliminary study comparing white, green, red and blue phosphors indicated that the colour of a monochrome display was unimportant. The only effect was an increased variability when red or blue was used. Observers preferred a green or white screen. For this study the colour display simulated a monochrome display with a white phosphor.

The observers used a joystick to indicated their responses. Additional communication between the experiment control program and the observer was by means of a Hewlett Packard video display terminal.

Stimuli

The stimuli were simulated FTI displays, 'x' frequency bins wide by 'y' time bins high, surrounded by a mid-grey rectangular border 20 pixels wide. Each "bin" was one pixel wide by one scan-line high. The values for 'x' and 'y' depended on the experimental conditions. The target was a single line, extending the entire height of the FTI display and was always one frequency bin wide, with no side-lobes. Its position in 'x' was randomly varied from trial to trial. The intensity of each pixel in the FTI space was obtained from a Gaussian distribution. Those pixels through which the target line passed were given a fixed increment whose value depended on the desired signal-to-noise ratio for the line. The actual screen brightness was controlled by lookup tables in the RDS, adjusted so that all values below the mean of the Gaussian distribution were displayed at zero brightness, and values above the mean were scaled linearly with the numeric value of pixel intensity.

For the first part of the study, the target was always a vertical line (equivalent to a fixed frequency signal). In the second part, the target frequency was time-varying and unstable as depicted by making the target line non-vertical and by introducing fluctuations in the average slope over the height of the display. The algorithm used to generate the fluctuations, and examples of the results, can be found in Appendix A. The average slope of an unstable time-varying target line was always within two degrees of vertical.

---

[1] UNIX is a Trademark of Bell Laboratories.

Each display contained a cursor whose position was controlled by the observer using a joystick. For stable vertical target lines the cursor was a pair of bright vertical lines that could be moved across the top and bottom grey border areas of the display. For the unstable time-varying target lines an 'x'-shaped cursor with the centre removed was used. It could be positioned at any point in the FTI display.

Conditions

The experiment measured the detectability of a single target line as a function of the number of time bins displayed and the ORing ratio. The number of time bins displayed was 20, 40, 80, 160, 320, or 400 for stable vertical target lines and 20, 40, 80, 160, or 320 for unstable time-varying target lines. Three ORing conditions were tested - 1:1, 2:1, and 4:1, For the three ORing conditions the display widths were respectively 324, 162, and 81 pixels. To simulate ORing, the intensity at each of the 324 bins was generated on each trial; the most intense pixel of each group of K successive pixels was displayed, where K corresponded to the ORing ratio.

Not all display lengths were tested under all ORing conditions. One of the primary aims of the ORing study was to determine the effect on performance of overall display area (total number of pixels displayed). Thus, in the initial study with stable target lines, different display areas rather than different display lengths were studied as a function of ORing ratio. Three different display areas were presented at each ORing ratio– 6480, 12960 and 25920 pixels. The corresponding display lengths were 20, 40 and 80 bins with 1:1 ORing, 40, 80 and 160 bins with 2:1 ORing and 80, 160 and 320 bins with 4:1 ORing. In addition, a condition was run with 400 time bins using 1:1 ORing. In the second part of the study, using unstable time-varying target lines, four history lengths were tested with three ORing ratios in a factorial design.

Procedure

Observers could carry out runs at their convenience, providing the laboratory was available and the computer was operational. An observer initiated the experiment by logging onto the computer using a special login command. The experiment control programme asked for the observer's name and set up the appropriate condition from information stored in a control file for the observer. At the start of a run of trials, the observer adjusted the room lighting and the screen brightness and contrast to suit deliberately vague criteria. They were told that the individual dots should seem small and crisp, that the background raster should be at threshold, and that the room illumination should be moderate. The reason for not controlling either room illumination or screen brightness was that it better simulated operational conditions to allow "operator control" over these variables. It also permits generalization of the results across these variables, within the range used by the observers. Observers were seated at approximately twice the normal viewing distance from the screen (1 metre) in order to simulate the visual angle of

pixels on a 1024 by 1024 display.

Each trial consisted of the following steps:

- The FTI display area within the mid-grey rectangle was filled with noise and the single target line, which spanned the display area at a randomly chosen 'x' position not closer to the edge of the border than 20 frequency bins.
- The observer moved the cursor freely until satisfied that it was aligned with the target, and then pushed a microswitch located on top of the joystick.
- Feedback was given in the form of a beep if the cursor had been correctly placed when the microswitch was pressed.
- The display for the next trial was immediately presented. The trial number was always displayed on the screen of the terminal used for logging on to the computer.

A "run" consisted of several "run-in" trials and 40 formal trials. The target location, slope (for unstable lines) and frequency and the background noise were varied randomly from trial to trial. Target intensity was varied according to the rules of the "PEST" psychophysical procedure (Taylor and Creelman, 1967). PEST is an adaptive procedure designed to keep a particular target parameter, in this case intensity, near a designated threshold, in this case 80% correct. If there are too many mistakes, the task is made easier; if too few, it is made more difficult. PEST has been shown to be both efficient and robust for measuring detection performance (Taylor and Creelman, 1967, Taylor, Forbes and Creelman, 1983). During the run-in trials, the intensity was reduced following a set of two consecutive correct responses, and increased following each error. The run-in phase was terminated after the observer had made at least two errors, followed by two consecutive correct responses.

The criterion for a correct response was a function of the ORing ratio because of the increased probability on the narrower (ORed) displays that the observer could correctly guess the location of the signal without actually seeing the line. The cursor had to be placed within a distance that remained proportionately constant as the display width narrowed, except that the criterion was never made more stringent than 2 pixels. Two pixels represents a reasonable limit for the unavoidable inaccuracy of manipulating the cursor with the joystick. In practice, the criterion was 5 pixels for the 1:1 ORing condition and 2 pixels for the 2:1 and 4:1 ORing conditions. An examination of the trial by trial responses indicated that in all conditions the observer usually positioned the cursor within 1 or 2 pixels on correct trials and was usually more than five pixels away from the target on incorrect trials.

RESULTS

The results of the experiments are shown in Figures 2 through 5. The performance of the different observers was similar. Thus, only average performance across observers along with standard deviations were plotted. Typically, the standard deviations were less than 1 dB. Exceptions were due to a few aberrant data points rather than to substantial differences amongst subjects.

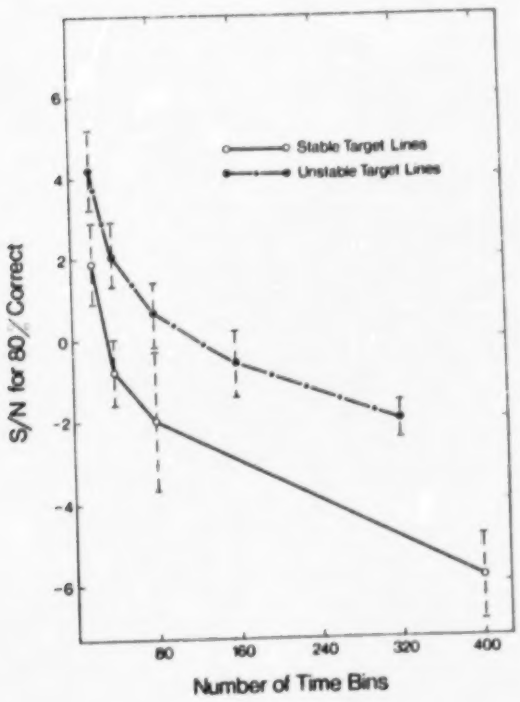

FIGURE 2: Effect of number of time bins on detection of stable vertical target lines and unstable time-varying target lines masked by gaussian noise, on a simulated FTI display. The standard deviations for each mean have been plotted as well.

Figure 2 shows the average performance without ORing for the two classes of target as a function of display length. The difference in detectability between the two types of targets was approximately 2.5 dB. This value is of little importance. It can be manipulated by changing the variables in the algorithm used to generate the unstable lines. What is important is whether changes in detectability as a function of history duration are similar, independent of differences in detectability. It appears that they were in this study. Performance improved at a rate of approximately 1.5 dB per doubling of the number of time bins once the number of time bins exceeded 20. In practical terms, the per time bin improvement in performance dropped off rapidly as display length was increased beyond about 80 lines.

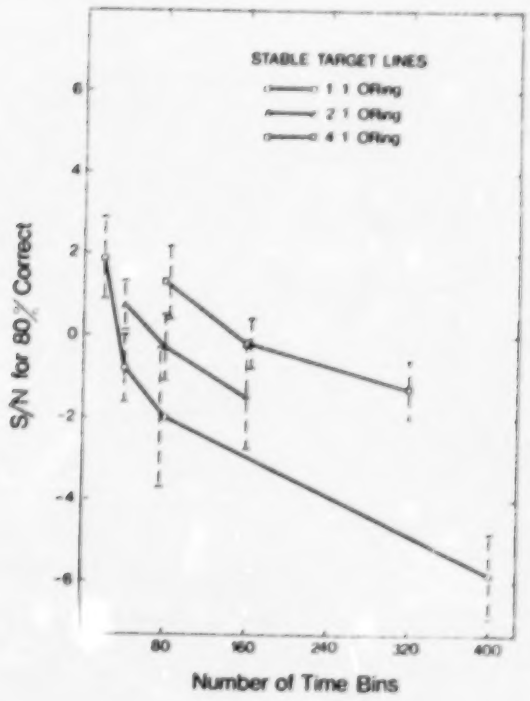

FIGURE 3: Effect of ORing ratio and number of time bins on the detection of a stable vertical target line masked by gaussian noise, in a simulated FTI display.

Figures 3 and 4 show the average performance in the different ORing ratios as a function of display length. The effect of ORing was similar to that found for display length. At most display lengths, 2:1 ORing led to a 1.5 dB decrement and 4:1 ORing to a further 1:5 dB decrement in performance as compared to that found with 1:1 ORing. At short display lengths, particularly the 20 bin condition, and with unstable lines, much smaller differences were found with ORing. In these conditions, the display length appears to have been the overriding factor, and ORing cause little further decrement.

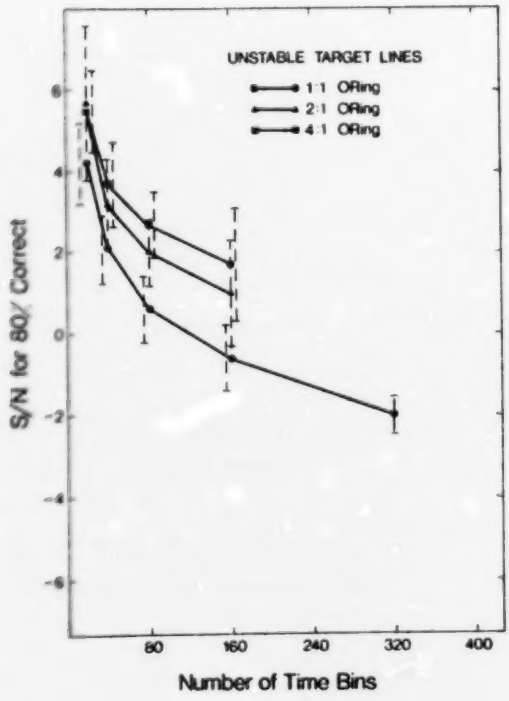

FIGURE 4: Effect of ORing ratio and number of time bins on the detection of an unstable time-varying target line masked by gaussian noise, in a simulated FTI display.

The data in Figures 3 and 4 have been replotted in Figure 5 as a function of the log of the total display space utilized. The results indicate that for display lengths in excess of 20 bins and for the ORing ratios studied, detection performance was a function of the total display space.

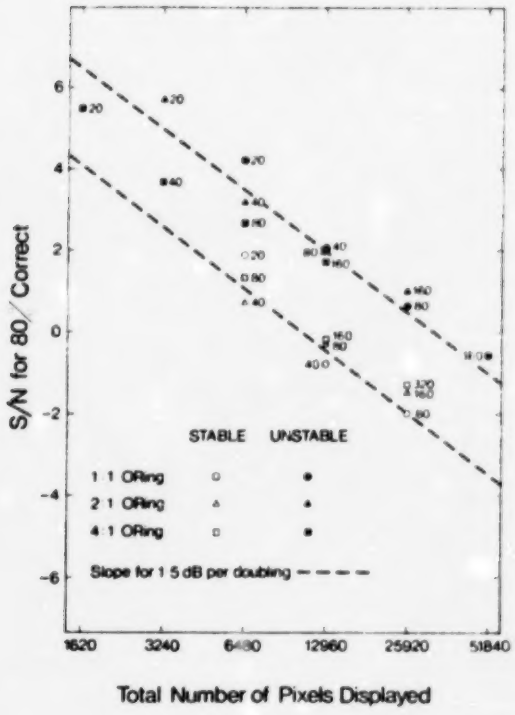

FIGURE 5: Detectability of a stable vertical target line and an unstable time-varying target line masked by gaussian noise as a function of total display space. The ORing ratio and history duration of each data point is indicated by symbol shape and by notation respectively.

DISCUSSION

At least for simple detection, the effects of reducing display area by limiting history and by ORing were similar, for history durations between 40 and 320 time bins. Displaying fewer than 40 time bins degraded performance substantially. The effect of ORing when more than 320 time bins are displayed was not tested. In practice, long histories are probably not worth having, because interesting targets are unlikely to be stably detectable for long periods. It is probably reasonable to limit display lengths to 80 bins rather than to apply strong ORing to longer displays.

The study was limited in a number of ways. The largest ORing ratio studied was 4:1. Larger ORing ratios might be considered, but they would be useful only with larger frequency ranges than the one simulated here. A wider frequency range might affect performance in other ways, because of the increased processing time required.

The study examined detection of a single target line in white noise. In practice, the operator would need to detect a number of lines and to discriminate new lines from existing lines rather than from a random noise background. Planned studies will examine detection under more realistic conditions.

CONCLUSION

Reducing the area used to display a given amount of information in the frequency-time-intensity format is accompanied by an increase in the signal level needed for detection. Provided that there are at least 40 time bins of history, however, it does not matter whether the reduction in display area is achieved by truncating the history or by frequency ORing. The important parameter is the total number of pixels displayed (number of frequency bins per time sample times the number of time samples). Halving the display area causes approximately 1.5 dB reduction in detection performance.

The experiments described here were done using a display capable of only 512 pixels per line, and in fact only 324 were ever used. Displays in modern sonar displays should be capable of 1024 pixels per scan line. The conclusions of this study should be used with caution when the number of pixels per time bin increases much beyond 300.

When ultimate sensitivity of detection is required, it is preferable to display maximum history with no frequency ORing; but when sensitivity must be sacrificed to the need for display space, no display should have less than 40 time bins. Allowing for a border of 10 scan lines between beams, a 1000-line display could show as many as 20 beams at once. The relationship between number of beams per display and detection remains to be determined, and no recommendations can be made as to the format of a multibeam display.

REFERENCES

TAYLOR, M. M. & C. D. CREELMAN. PEST: Efficient Estimates on Probability Functions. *J. Acoust. Soc. Amer.* 41, 782-787, 1967.

TAYLOR, M. M., S. M. FORBES, & C. D. CREELMAN. PEST Reduces Bias in Forced Choice Psychophysics. *J. Acoust. Soc. Amer.* 74, 1367-1374, 1983.

TAYLOR, M. M. & J. A. NORTON. A Versatile Colour Raster Display System for Visual Psychophysics and Image Processing. *Proceedings of the Digital Equipment Computer Users Society Canada*, 3, 923-929, 1977.

APPENDIX A

GENERATION OF UNSTABLE LINE TARGETS

The unstable time-varying target lines used in the experiment varied in slope and initial frequency from trial to trial and in the extent to which they approximated the average slope from time sample to time sample. The moment to moment variation was determined using the following algorithm:

$$P[i] = (P[i-1] \times \rho) + (PF[i-1] \times (1-\rho)) + R + \Delta$$

Where:

- P[i] the actual location of the target along the scan-line i.
- PF[i] the position of the target given by the intersection of the scan-line i with a straight line of specified slope.
- ρ a fixed value between 0 and 1.
- R a value randomly selected from a gaussian table with a mean of zero and a S.D. of 1.25.
- Δ the nominal slope of the line.

For the reported studies ρ was .9875. A preliminary study used a ρ of 0.5 as well. The smaller ρ produced lines with rapid deviation from the nominal slope, while the chosen ρ produced slower longer deviation from the nominal slope. Figure A1 shows examples of the targets lines produced.

The algorithm allowed the generation of unique target samples from trial to trial with a controlled and reproducible degree of instability, allowing the testing of the effect of display size on different types of targets.

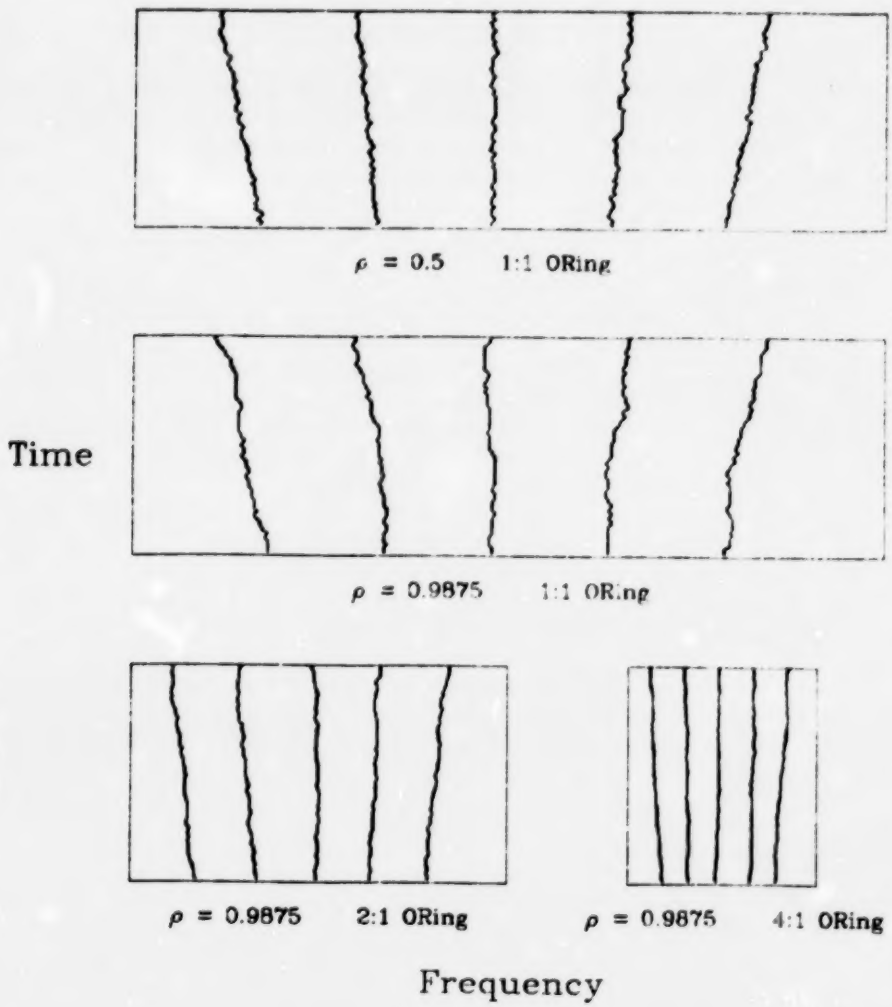

FIGURE A1: Examples of unstable time-varying target lines generated by the algorithm outlined in the text. In the experiment reported, only a ρ of 0.9875 was used. The slopes shown range from -0.2 to 0.2. The effect of ORing ratio on the slope and variability of the targets is also illustrated.

APPENDIX B

GLOSSARY

Frequency- Time- Intensity Display (FTI) - A visual display of the energy present in a sound at a specified set of frequency bands over a specified period of time. The display presents frequency along the horizontal dimension, time along the vertical dimension and intensity as the brightness (on a CRT) or darkness (on paper) of each point on the display.

Time bin - A visual display of the acoustic energy received over a specified unit of time. In an FTI display, a time bin would be a single vertical line on the display.

Frequency bin - A visual display of the acoustic energy received at a specified band of frequencies. In an FTI display, a frequency bin would be a single horizontal line on the display.

Multi- beam Sonar System - A sonar system that can extract information from different sectors of the ocean separately. The sectors are called beams.

ORing - A method of data reduction that involves identifying the frequency bin containing the most energy among 'N' contiguous frequency bins. The method may also be applied to time bins or contiguous beams.

Scan line - Single horizontal line on a CRT.

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, Post Office Box 2000
Downsview, Ontario, Canada, Telephone (416) 633-4240

POOR

QUALITY

ORIGINAL